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http://dx.doi.org/10.5339/qfarc.2016.EEPP2189

Identifying Optimal Design of Office Buildings Using Harmony Search Optimization Algorithm

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Energy is an expensive and scare resource and the world faces an energy crisis given our dependence on the limited supply of fossil fuels. Similar to other countries, in Qatar, energy consumption and the subsequent production of greenhouse gas emissions are becoming a major challenge that the society is facing. Recent statistics in Qatar indicated that the per-capita use of electricity and production of CO_2-emission has been rising continually since 1971. Population growth and industrial development are the main sources of these problems. In 2004, the electricity consumption per capita reached 17000 kWh which puts Qatar as one of the highest energy consumer per capita in the world as it surpasses the average per-capita electricity consumption of the developed countries. Due to the high contribution of buildings in overall energy consumption, building energy performance has become a key approach to reduce energy consumption and the associated greenhouse gas emissions. Since the building energy performance depends on the numerous variables related to the building characteristics, installed equipment, occupants' behavior, and environmental loadings, selecting the most efficient combination of variables is highly complicated. Considering other objectives such as reduction of financial costs and minimizing the life cycle emission will increase the complexity of the decision making process. To solve these problems, different numerical methods such as optimization algorithms are proposed and utilized. Multi-objective design optimization is a powerful tool to assist decision makers identify and implement the most efficient strategies. The multi objective optimization algorithms are capable of determining the proper variables to obtain the optimum design. Therefore, the objective of this work is to tackle the problem of determining the best design by implementing a harmony search (HS) based optimization algorithm to minimize the life cycle cost and life cycle CO_2 equivalent emissions of a small office building. Parameters considered in the current investigation model are building materials and their associated thickness in different building components including wall, floor, roof, and ceiling. In addition, different HVAC systems are considered as

Cite this article as: Asadi S, Mostavi E, Boussaa D. (2016). Identifying Optimal Design of Office Buildings Using Harmony Search Optimization Algorithm. Qatar Foundation Annual Research Conference Proceedings 2016: EEPP2189 http:// dx.doi.org/10.5339/qfarc.2016.EEPP2189.

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design variables. HS algorithm was conceptualized using the musical process to identify the perfect state of harmony. HS was initially developed for the discrete variable optimization problems and then expanded to include continuous variable problems as well. Simplicity in implementation and flexibility of the algorithm has increased the utilization of this method in many research fields. In difference with other optimization methods which are usually based on the numerical linear and nonlinear programing methods that require gradient information to seek the solution, HS algorithm does not utilize gradient information.
To achieve this objective, price data and emission data are collected and magnitudes of each one calculated according to the simulation results. The first objective is to minimize the life cycle cost of the design. To identify the life cycle cost of each model, the summation of present value of initial costs, operation and maintenance costs, and energy costs are calculated. The data for construction costs are taken from construction handbooks. In this study, the building life is assumed to be 40 years. For the life cycle assessment, all phases of pre-use (extraction, transfer, and processing of materials), use (service and maintenance), and end-of-life (demolishing and transfer of wastes) of the modeled building have been considered. The pre-use phase costs include the material prices, labor costs, replacement, and equipment. The use-phase includes the service energy costs (heating, cooling, water heating, lighting, equipment, etc.) which are determined by the energy simulation. The second objective of this study is to minimize the life cycle emission of the design. The life cycle emission of each design is determined based on the emission of global warming potential (GWP) data of different materials during pre-use, use, and end-of-life. The pre-use emission can be calculated by having the weight of each material used in construction of the building and multiplying with the emission amount per unit weight. The environmental emission data are collected through different LCA datasets such as DEAM and EcoPack. The use phase emission includes two types of emissions: energy related and service-maintenance. For the energy related emissions, the emission factor of electricity consumption is determined according to the location and source of energy generator systems. To calculate the maintenance emission during the use period, a list of materials and mass of each which should be replaced was prepared. The post-use phase energy consumption includes all the emissions related to demolition and disposal of wastes and the regarding data were gathered through life cycle analysis data bases. In order to optimize the process of designing of the small office building in this study, a C++ code which is capable of modifying model characteristics, perform energy simulation, evaluate the results, and identify the next simulation magnitudes was developed. The proposed HS optimization algorithm, first selects and assigns random magnitudes for the initial values of variables. This selection is a random selection through the defined ranges for variables. Then a simulation of the initial model is performed to attain the first sets of results (objective functions). HS algorithm evaluates the objectives and sets the new values for variables for next simulation. The results of next simulations will be compared with results of previous simulations. If the results in each simulation are better than worst solution, worst solution will be replaced by new results. The solution of the optimization problem improves by having multiple simulations gradually. To determine the energy consumption of the building in the use phase, EnergyPlus model of the building including building envelope system details, thermal zones temperature set points, occupants' activity type and schedule, types of HVAC system, equipment loadings, lighting system schedule, and design year weather data was prepared. EnergyPlus is a powerful energy simulation program for modeling building energy performance and capable of modeling multi-zone airflow, thermal comfort and natural ventilation systems, as well as determining the amount of energy was utilized to determine the total building energy consumption. The focus of this study is to determine the optimum building construction materials and their associated thickness as well as HVAC system of a small office building located in Doha, Qatar. Heat pump air to air ventilation system is assigned to this building and zones' temperature set points are fixed on 22 °C for heating and 26 °C for cooling. Running the simulation process parallel to the optimization algorithm evaluation resulted in identifying multiple optimum solutions of building construction materials and their associated thickness as well as HVAC system.
In order to offer decision makers the chance to evaluate the tradeoff between cost and emissions, the Pareto front is plotted. In addition, comparing designs with different life cycle costs and emissions resulted in the following conclusions: By comparing the life cycle cost and carbon dioxide emission of different designs, it was concluded that assigning a small modification in life cycle cost can significantly change the CO_2 equivalent emissions. Foundations, floors, and ceilings are emitting the highest amounts of carbon dioxide

equivalent in building. Using of high emission materials with higher thickness comparing to other construction materials are the main reasons of this contribution. The outcomes of this research, assists designers in identifying the best combination of envelope materials to design energy efficient buildings. It remains for future to investigate the effects of working schedule, and control strategies in optimum design of buildings.